Futures 102 (2018) 89–103

Contents lists available at ScienceDirect

Futures

journal homepage: www.elsevier.com/locate/futures

Measuring changes in urban functional capacity for climate resilience: Perspectives from Korea

Donghyun Kim*, Seul-Ki Song

Korea Environment Institute, 370 Sicheong-daero, Sejong, 30147, Republic of Korea

ARTICLE INFO

Keywords:
Urban resilience
Climate resilience
Urban function
Resilience indicators
Climate change adaptation

ABSTRACT

The purpose of this study is to measure urban resilience through indicators related to urban function and to classify 232 cities in Korea with regard to climate variability. Urban functions were classified into basic, developmental, sustainable, and maintenance functions, and were measured using 25 indicators. Confirmatory factor analysis was used to integrate each function into a single value. Cluster analysis was applied to 232 cities in Korea and analyzed for the years 2000, 2005, and 2010. The analysis revealed that clusters appeared between variables centered on metropolitan cities and variables of climate variability. In 2000 and 2005, Korean cities had similar clusters, but in 2010, they manifested a different pattern. This study suggests that the construction and accumulation of time-series data is necessary for understanding the lack of each function of the city in constructing adaptation policies for communities.

1. Introduction

The German sociologist Ulrich Beck (1992) suggested that the concept of resilience in at-risk societies was being discussed as a new approach to exogenous change in a situation of increased complexity, connectivity of society, and an unpredictable future (Leach, 2008; Berkes, Colding, & Folke, 2003; Wilkinson, Porter, & Colding, 2010). The current discourse on resilience is diverse, appearing in realms such as physics, biology, network engineering, civil engineering, psychology, economics, and urban planning (Brand & Jax, 2007; White & O'Hare, 2014). Although the conceptual scope of resilience varies by field, engineering limits it to a particular target and clearly defined exogenous impacts (Kim & Lim, 2016; Davoudi, 2012). Moreover, in psychology and economics, the discourse on resilience focuses on the systematic changes and targets that it encompasses, and limits types of shock to phenomena such as trauma and economic crises (Bonanno, 2004; Simmie & Martin, 2010; Vale & Campanella, 2005).

Among the many exogenous changes in risk society, climate change is particularly unpredictable, uncertain, and significant (Seeliger & Turok, 2013; Zhao, Chapman, Randal, & Howden-Chapman, 2013), and it is considered a major exogenous shift for cities (Osbahr, 2007; Satterthwaite & Dodman, 2013). Climate change relates to exogenous transformations in urban resilience and shock; urban resilience is employed as a concept of sustainable metropolitan growth (Carmin, Nadkarni, & Rhie, 2012; Leichenko, 2011). Thus, the notions of urban resilience and urban climate resilience do not derive from different categories but in fact overlap. They both relate to the obstacles facing cities and their functional capacity to respond to change.

Urban resilience deals with how climate change and cities relate to one another. Knowing the climatic conditions of a city is considered a prerequisite for building urban functions such as infrastructure, social networks, and an economy (Wilkinson et al., 2010). Climate change can impact conditions that are not otherwise easily changed and are considered external changes with patterns similar to past conditions (Kim & Lim, 2016). Understanding urban climate resilience requires some questions to be answered. Does it

* Corresponding author.
E-mail addresses: donghyunkim@kei.re.kr (D. Kim), sksong@kei.re.kr (S.-K. Song).

https://doi.org/10.1016/j.futures.2018.05.001
Received 5 May 2017; Received in revised form 27 March 2018; Accepted 20 May 2018
Available online 21 May 2018
0016-3287/ © 2018 Elsevier Ltd. All rights reserved.

mean to return to the original state before risk, to accept exogenous change, or to move toward a better state? What is the scope of the object that one aims to return to? Does it incorporate social elements that are important in urban planning? (Friend & Moench, 2013; Pizzo, 2015). Such discourse has provoked a demand to find new ways of measuring urban resilience (Kim & Lim, 2016).

This study aims to measure urban resilience through indicators related to urban functions and to understand changes by linking those indicators to climate variability. Urban functions connected to urban resilience were operationally defined and relevant indicators were created. Indicators and measurement variables for these urban functions were constructed by nine experts for each urban function considering Korea's circumstances via the Delphi method. The measurement variables were integrated into the indicators through confirmatory factor analysis (CFA). The drawn indicators were applied to the years 2000, 2005, and 2010, using statistical data from 232 Korean cities. Climate variability was classified using factor analysis. The data on climate variability was collected from the Korea Meteorological Administration, 2012, which assessed climate change variability using the Representative Concentration Pathway (RCP) scenarios provided by the Intergovernmental Panel on Climate Change (IPCC). The 232 Korean cities were clustered based on the drawn indicators of urban resilience and climate variability. Finally, this study suggests implications for the climate change adaptation policies of local governments. This analysis provides a framework for local policymakers to understand how the functional factors that make up cities change over time from a methodological viewpoint. Analysis of the clusters is distilled into suggestions for ways in which local governments may develop climate change adaptation policies. Local policymakers can use the methods and results of this study to the state of their city and improve the resilience of their urban systems to exogenous change (climate change).

This study targeted Korean cities. From the 1960s to 1980s, Korean development focused on physical infrastructure development with rapid economic growth. In the past, urban planning and policy in Korea had focused on supporting physical development to accommodate the population rather than exogenous risk. However, in recent years, exogenous changes and risks, such as depopulation, aging society, climate change, and disasters, have been emerging, and thus, it is important for urban planning to reflect the various components of the urban system. In particular, the impacts of climate change, such as heatwaves and heavy rainfall since the 2000s, are changing the direction of urban planning, but there is no index to diagnose the changed conditions and support plans and policies. Although this study focuses on Korea, it can provide implications for developing countries where rapid growth and development and the impacts of climate change are occurring simultaneously, and where resilience needs to be reflected in urban planning and policy.

For the purpose of this study, we review relevant literature and provide a theoretical discussion on climate change, urban resilience, and urban functions in the second section. In the third section, we describe the methods and materials used for the analysis, and then demonstrate the results of the analysis in the fourth section. Finally, we provide a conclusion and suggest implications for policy makers.

2. Theoretical discussion

2.1. Urban resilience and climate change

Meerow, Newell, & Stults, 2016 conducted a meta-analysis of 239 key papers on urban resilience. They explored the tensions between the conceptual constructs of urban resilience and provided an operational definition of the term. They identified six conceptual tensions of urban resilience: (1) the definition of the term "urban"; (2) the understanding of equilibrium; (3) resilience as a positive notion; (4) positive versus neutral (or negative) conceptualizations of resilience; (5) adaptation versus general adaptability; and (6) timescale of action. The sixth tension relates to how a city should be defined and how its characteristics should be classified.

The discourse on urban resilience contains a controversial debate over whether climate change should be considered a threat or impact on its own, or included in urban resilience (Meerow et al., 2016). This leads us to the question of whether urban resilience and urban climate resilience can be discussed as separate ideas. Climate change causes mid- and long-term disturbances in uncertain ways, and although it does not impact particular sectors from the angle of urban resilience, it is difficult to clearly distinguish between urban resilience and urban climate resilience (Kim & Lim, 2016). Studies on urban resilience have yet to clearly portray its nature and the extent to which it exists in cities; hence, the definitions of targets for measuring urban and urban climate resilience remain unclear (Meerow et al., 2016).

Although definitions of targets for measuring resilience remain vague, prior research has formulated "the city" in two ways: (1) As a complex, self-contained system; and (2) As a series of networks. In the first viewpoint, a city consists of social, technological, and ecological features that change over time and follow certain patterns. Some previous studies have examined the dynamic aspects of the changes in a city's characteristics (Smith & Stirling, 2010). The second viewpoint considers the connections among a city's various networks as fundamental to how it is shaped (Brugmann, 2012; Da Silva, Kernaghan, & Luque, 2012; Desouza & Flanery, 2013). All physical and social networks are included in the shifts in a city's dynamic links.

Kim and Lim (2016) presented a framework for understanding urban resilience from the angle of climate change considering various perspectives on resilience. Their framework portrayed the links between climate change and urban resilience as follows: (1) A disturbance system related to climate change; (2) The transition process of the urban system; and (3) A preemptive and reactive process. The first aspect describes a sudden change that can act as a stressor or shock to the urban system, causing irreversible and ongoing transformations. The second aspect refers to transforming the current urban system into new systems through the changes in each functional sector of a city (e.g., transport, water, and housing) and the interactions of their sectors. The likelihood of a transition depends on a city's capabilities; adaptation is the ability to make a transition via disturbances and change. The preemptive and responsive process relates to the discourse on engineering resilience, which is linked to reducing disaster risks. Moench, Tyler, &

Lage, 2011 presented a framework for understanding urban climate resilience. With the goal of diagnosing climate vulnerability and creating a plan for urban resilience, this framework simplifies the complex relationship between urban residents and systems, institutions, and climate change. Tyler et al. (2014) explored key elements of urban climate resilience by breaking it down into systems, actors, and institutions. These fundamental aspects include redundancy, diversity, modularity, decision-making, information, and learning procedures; using these, Tyler et al. (2014) linked the measurements of the sub-systems that comprise a city's sectors.

2.2. Urban functional capacity and resilience

The notion of urban composition needs to be understood in order to evaluate the functional capacity underlying urban resilience. Prior studies on resilience have viewed cities as complex systems that comprise various networks (Da Silva et al., 2012; Lu & Stead, 2013), including physical and social ones (Godschalk, 2003).

classified urban complex systems relating to resilience into four parts: (1) Socio-economic dynamics; (2) Urban infrastructures and forms; (3) Networked materials and energy flows; and (4) Governance networks. Socio-economic dynamics are composed of factors relating to urban socio-economic capabilities. In urban infrastructure, forms are based on facilities that have physical networks, which are discussed metaphorically as comprising a city's metabolism (Resilience Alliance, 2007). Governance networks include various actors that form various urban systems such as laborers, non-governmental organizations (NGOs), and enterprises (Dicken, 2011).

Toubin et al. (2015) focused on urban services and networks when discussing urban resilience. Urban services are key to building urban systems; support functions include the urban economy, society, and housing (Bruneau et al., 2003). Technical networks and groups of actors are related to urban services, and urban resilience focuses on the ability to promote and maintain the supply and function of services.

In terms of applying the framework for the key elements of systems, actors, and institutions, Tyler et al. (2014) divided urban functions into seven parts: (1) Water supply; (2) Flood prevention and drainage; (3) Public health; (4) Tourism; (5) Solid waste management; (6) Ecosystem management; and (7) Resettlement and Housing.

The Rockefeller Foundation and ARUP Group (2014) broke down the functions that maintain a city into eight elements linked to resilience: (1) Providing resources for basic needs; (2) Protecting people's lives; (3) Protecting and maintaining assets; (4) Protecting human relationships and identities; (5) Promoting knowledge; (6) Education and innovation; (7) Protecting law, justice, and equity; (8) Livelihood security; and (9) Economic prosperity.

Yañez (2012) divided urban systems into three dimensions: (1) Infrastructure networks; (2) System networks; and (3) Knowledge networks. She then linked these elements with the constructs of resilience, which include diversity, flexibility, interactions, and responsiveness.

Burton (2012) explored the notion of the city by classifying it into six aspects: (1) Society; (2) Economics; (3) Institutional constructs; (4) Infrastructure; (5) Community; and (6) Environmental systems. These elements include social competence, community health and wellness, homogeneity and fairness, economic and life stability, resource capital, economic diversity, economic infrastructure, risk mitigation plan, the degree of development, housing type, infrastructure risk exposure, creative class, social capital, and environmental sustainability.

Composite resilience indicators based on statistical data were used in many studies. Hung, Yang, Chien, and Liu, 2016 drew and measured climate hazard resilience indicators. They employed 25 sub-indicators, which were classified into: (1) Inherent biophysical conditions; (2) Inherent socioeconomic conditions; (3) Institutional, coping, and infrastructural capacities; and (4) Adaptive capacities and learning. Shim and Kim (2015) meanwhile categorized urban resilience into the following general categories: (1) Biophysical; (2) Built environment; and (3) Socioeconomic; they used 16 indicators within these to gauge resilience against natural disasters. Kotzee and Reyers (2016) formed indicators by using 23 variables for flood resilience. The aforementioned frameworks for measuring urban resilience developed by the Rockefeller Foundation and ARUP Group (2014), Tyler et al. (2014), Yañez (2012), and Burton (2012) also used a similar method to construct resilience indicators.

A city's constructs can be divided into three types: (1) *Collective characteristics* such as urban and socioeconomic features, including population, capital, the local economy, education, and human capital; (2) *The built environment and network characteristics*—a city consists of various kinds of infrastructure such as public facilities, physical targets, and flows, and it is not possible to distinguish between urban infrastructure, form, and networked materials; and (3) *Invisible features of socioeconomic networks*, related to governance networks based on people's behaviors and interactions and including innovation, sharing, and knowledge.

Previous studies attempting to measure the concept of urban resilience have suggested that there are gaps in the relationship between conceptual attributes and measurement variables, as well as in the constraints of statistical data. Toubin et al. (2015) identified a gap between the conceptual attributes of resilience and the attributes of actors in measuring the concept of resilience. The Rockefeller Foundation and ARUP Group (2014) constructed indicators as performance-based approaches to reflect cultural and social networks that affect human behavior in order to address the limitations of asset-based approaches that focus on physical assets. Yañez (2012) suggested that it is not easy to measure the resilience process as an indicator because of different scales and perspectives in the urban system, which is composed of the interactions of infrastructure, institution, knowledge, and ecosystem. Shim and Kim (2015) argued that the problem of the practical constraints of statistical data and factor of theoretical concept of resilience are institutional elements. Kotzee and Reyers (2016) and Hung et al. (2016) propose that there is a gap between the concept of resilience and its measurement, but they emphasize that policy makers should be responsible for determining the role of the tradeoff between these factors and suggest that there is a need for further study to identify the causes of this tradeoff.

Both qualitative and quantitative methods have been proposed as means of reducing the gap between concept and measurement

Table 1
Function classifications for measuring and defining urban climate resilience.

Function category	Definition	Sub-composition
Basic function	The most basic function relates to urban residents' minimum needs, i.e., the necessities of life.	Housing, production, consumption (commerce), jobs
Developmental function	This is based on the mutual relationships that are required to help residents prosper and to ensure the human capital of future generations. This means that people need to actively and continuously accept new things.	Innovation, social interactions, education, creativity
Sustainable function	This function ensures that people, society, and the economy function well for longer periods of time. Space for living is required.	Culture, leisure, the environment, medical care, welfare, social safety
Maintenance function	This involves institutional infrastructure, infrastructure, and the physical networks that make up a city, in addition to social and physical complexes and maintenance.	Politics and participation, public administration, disaster prevention and safety, public infrastructure

variables of indicators in the measurement of resilience. NOAA (2015), the Rockefeller Foundation and ARUP Group (2014), Georgetown Climate Center (2017), and Maryland Coast Smart Council (2017) use questionnaires or interviews with policy stakeholders on institutional aspects of the concept of resilience, focusing on behavior and cognition. Such qualitative measurements face issues with the subjective judgment of the evaluator and/or objectivity in comparing results. In the case of quantitative methods, statistical data is used to construct the measurement variable of indicator and standardized to evaluate it as a comprehensive index. Although it is easy to overlook the institutional capacity and process emphasized in resilience, it is advantageous to understand the tradeoffs between the factors that constitute resilience and their current status.

3. Methods and materials

3.1. Operationalization, indicators, and data

This study operationalized a city's functions and composition, as shown in Table 1. The divisions of function include the characteristics for maintaining a city's basic services and developing capacities to absorbing future impacts and stress from climate change disturbances (Seelinger & Turok, 2013).

Table 2 presents the indicators, measurement variables, and measurement method used, along with the data. The indicators and measurement variables were drawn up by nine experts using the Delphi method. These experts were selected from among university professors and researchers with doctoral degrees; each expert chosen had experience conducting research on urban resilience in Korea. The indicators were selected through a three-step process. For the first step, each expert suggested indicators to gauge urban resilience based on the functional categories in Table 1, the indicators and indexes of previous studies, climate change adaptation, and concepts of urban resilience. For the second step, each expert evaluated the indicators recommended by one of the other experts. For the third step, the common indicators among those suggested by each expert were selected considering available statistical data.

This study has limitations in that some variables are weakly correlated with indicators due to problems related to statistical data acquisition in the composition of variables that measure indicators. For example, in the case of the foundation of social capital in the development function, we wanted to find out the measurement variables of capital and space that lead to the social participation of all people to meet the function of the city defined above. However, they could not find data consistent with the temporal and spatial scope of the study. We used the area ratio of the religious facilities as the social capital measurement variables proposed by Burton (2012) and Mayunga (2009). Likewise, in the case of Cohesion of the community of the sustainable function, we tried to find actual community cohesion measurement variables such as the number of people who could be helped in difficult times, but there were difficulties in obtaining data with this as well. Therefore, we used the ratio of the population who has lived in the area for more than 20 years as the measurement variable based on the residence period proposed by Campbell and Lee (1992) as one of the elements of Cohesion of the community.

3.2. Methods

The unit of analysis in this study is the city, which is here translated as *si-gun-gu*; the city enforces policies and organizes the boundaries of Korea's local government and independent council. A total of 232 units are employed. The 232 units used in this study consisted of the same range of spatial areas that can be compared over time according to the criteria presented by the National Statistical Office. In instances in which cities that were divided into different units in 2000 were consolidated into single units in 2007, we adjusted based on the integrated spatial domain. This study comprised the years 2000, 2005, and 2010, the years when population housing censuses were conducted; this data is the largest portion of all data used to measure the indicators.

The method for determining urban resilience and linking it to climate variability was organized into three steps, as follows:

(1) The process of standardizing measurement variables. The raw data of measurement variables for each indicator was organized and standardized as a Z value. Next, we used the Z value to standardize each measurement unit of the measurement variable. We converted each measurement variable to a value between 0 and 1 using mean and standard deviation. The CFA was then used to integrate the measurement variables, which were configured for each function into a single metric. In this step, the factor loading

Table 2
The variables used to measure and collect data on urban climate resilience, according to function.

Function	Indicator	Measurement Variable	Measurement Method	Data	Relationship
Basic function	1. Safety of residential buildings	Rate of deteriorated houses	Rate of houses built prior to 1980 among whole houses	Population and housing census	–
	2. Risk characteristics of residential locations	Dangerous areas	Sum of areas facing possible floods, landslides, and tsunamis	Ministry of Public Safety and Security	–
		Rate of vulnerable residents	Rate of homes below the minimum housing standard among all households	Population and housing census	–
	3. Adequate housing supply	Housing supply rate	Ratio of houses to households	Statistical yearbooks of local governments	+
		Occupancy type	Rate of households that own houses among all households	Housing surveys	+
	4. Productivity	Degree of local tax payments	Amount of local tax per capita	Local tax statistics	+
	5. Diversity of industry	Degree of specialization in manufacturing	Manufacturing rate of all businesses	Surveys on wages and working hours at establishments	–
		Diversity of industry	Business diversity index (Simpson index)	Surveys on wages and working hours at establishments	+
	6. Economic power of local governments	Available resources of local governments	Sum of local tax and non-tax receipt income	Statistical yearbooks of local governments	+
	7. Local industrial base	Local service workers	Number of local service employees among all workers (individual, wholesale, culture)	Surveys on wages and working hours at establishments	+
	8. Employment opportunities	Stability of job	Rate of full-time employees among all workers	Census on establishments	+
		Number of new jobs created	Number of new local jobs compared to the previous year	Surveys on wages and working hours at establishments	+
Developmental function	1. Knowledge-based industry	Foundation of creative industry	Number of research and development (R & D) enterprises per 1000 people	Census of establishments	+
		Degree of the foundation	Number of businesses started in applicable year	Census of establishments	+
	2. Innovation workforce	Professional science and technology services	Percentage of professional science and technology service workers	Census of establishments	+
	3. Innovative capital and level	R & D investment expenditure	R & D expenses of companies in the region	Surveys on R&D	+
		Total innovation index	Percentage of companies with innovative products, processes, and services	Korea Innovation Survey (KIS)	+
	4. Foundation of social capital	Religious facilities	Area ratio of religious facilities	Statistical yearbooks of local governments	+
	5. Educational opportunities and standards	Educational facilities	Number of kindergartens, elementary schools, secondary schools per 1000 people	Statistical yearbooks of local governments; Statistics on education	+
		Educational level	Number of people who studied at a four-year university or higher	Population and housing census	+
		Number of libraries	Number of public libraries	Library statistics	+
		Equity of education	Level of satisfaction with educational opportunities	Social surveys	+
	6. Influx of creative classes	Inflow of professional science and technology service workers	A year-by-year increase in the number of professional science and technology service workers	Census of establishments	+

(*continued on next page*)

Table 2 (*continued*)

Function	Indicator	Measurement Variable	Measurement Method	Data	Relationship
Sustainable function	1. Opportunities for culture and leisure	Satisfaction with culture and leisure	Level of satisfaction with leisure	Social surveys	+
	2. Cultural cohesion	Cohesion of the community	Percentage of people who have lived there for at least 20 years compared to all residents	Population and housing census	+
	3. Natural environment	Green zones and parks	Percentage of green zones and parks compared to the total area	Urban planning statistics	+
	4. Disaster damage	Degree of damage due to disasters	Total pieces of property damaged due to disasters	Statistical Yearbook on Natural Disasters (Ministry of Public Safety and Security)	–
		Mortality rate	Number of casualties due to disasters	Statistical Yearbook on Natural Disasters (Ministry of Public Safety and Security)	–
	5. Social safety foundation	Number of basic livelihood security recipients	Number of people receiving income support from the government for basic needs	Statistical yearbooks of local governments	–
		Fire and police stations	Number of fire and police stations	Statistical yearbooks of local governments	+
Maintenance function	1. Citizen participation	Degree of political participation	Turnout for elections (Turnout in the election closest to the year)	Election statistics (National Election Commission)	+
	2. Administrative budget and manpower	Administrative personnel	Number of public officials in the area	Statistical yearbooks of local governments	+
		Number of people working at administrative service agencies	Number of civil servants of lower administrative agencies	Statistical yearbooks of local governments	+
		Processing complaints	Total number of complaints per year	Statistical yearbooks of local governments	+
		Financial self-reliance	Rate of local tax and non-tax revenue compared to local government's total revenue	Statistical yearbooks of local governments	+
		Recovery grants	Self-restoration costs incurred due to disasters	Ministry of Public Safety and Security	+
	3. Degree of responses to disasters	Amount of damage due to natural disasters for 10 years	Total cost of damaged properties due to disasters in the past 10 years	Statistical Yearbook on Natural Disasters (Ministry of Public Safety and Security)	–
		Degree of recovery due to natural disasters for 10 years	Total cost of disaster recovery over the past 10 years	Statistical Yearbook on Natural Disasters (Ministry of Public Safety and Security)	–
	4. Disaster preparedness infrastructure	Drainage pumping station	Number of drainage pumping stations	Statistics of sewage	+
		Transportation facilities	Total area of connected roads in the region	Urban planning statistics	+

value for each variable was derived and consolidated into one variable for each function. In this process, the factor loading values are used as the weight of integration of functional variables.

(2) The indicators of climate variability were organized using the data from the Korea Meteorological Administration, 2012, which was based on the IPCC's RCP 8.5 scenarios and is used to estimate changes in climate values expected to occur during the last quarter of the twenty-first century (2071–2100) and to compare them with recent climate values (2001–2010). This data includes variables for each of the 232 target cities, such as average temperature (°C), maximum daytime temperature (°C), minimum daytime temperature (°C), annual precipitation (%), number of days with heat waves (days), number of days with tropical nights (days), intensity of rainfall (%), and number of rainy days (days). The purpose of doing so is to derive clusters that integrate the functions of urban resilience and the tendency of climatic factors in each city; therefore, we use standardized units of values, organized in a range from 0 to 1 using Z value. After standardizing the variables, the climatic factors were derived through factor analysis. Climatic factors are used to identify trends in climate change as exogenous changes that affect the urban resilience of the 232 spatial units.

(3) Each city was grouped through cluster analysis in terms of urban resilience indicators and climate variability. Hierarchical cluster analysis was employed to detect the number of clusters, and then k-means clustering was conducted via the number of clusters as the drawn number of hierarchical cluster analysis. Hierarchical cluster analysis is a method of tying each object together with the other nearest object; in this study, it was used to examine the first cluster through the dendrogram and agglomeration schedule. K-means clustering is a technique that first sets the number of clusters and draws them by repeating analysis until a mutually exclusive state in which an entity only belongs to one community is formed. Whether there is an average difference between clusters can be statistically distinguished through one-way analysis of variance (ANOVA). For clustering, Ward's method and squared Euclidean distance for intervals between the clusters were used.

In this study, clusters were classified by integrating climate variability and resilience indicators related to urban function. However, at the current level of analysis in this study, the causes of such changes cannot be known. The indicators can only present features of a phenomenon or situation; they do not explain scientific inference or causality (Schipper & Langston, 2013). The indicators for measuring resilience by city function as presented in this study also contain the same limitations.

4. Findings

4.1. Results of factor analysis of climate variability and the urban resilience indicators

Table 3 shows the results of the factor analysis of values of climate variability. The findings were compressed into the three following factors. (1) *A constant upward volatility of temperature*: Average temperature (°C), the maximum daytime temperature (°C), and the minimum daytime temperature (°C) apply here. (2) *Rainfall variability*: Annual precipitation (%), intensity of rainfall (%), and rainy days (days) apply here. (3) *High temperature volatility in summer*: The days with heat waves (days) and days with tropical nights (days) apply here.

Due to the CFA of the urban resilience indicators, the fit of the model is shown in Table 4. According to the criterion of fitness, the CFA model of all years had poor goodness of fit. However, given that the purpose of using CFA in this study is to combine the variables by function by calculating the weight in accordance with the degree of contribution between each measurement variable, the adequacy was higher than the simple average or sum of weights. Accordingly, factor load values were used, as shown in Table 5.

4.2. Cluster types of urban resilience and climate change

Table 6 shows the results of exploring cluster forms through hierarchical cluster analysis. Except for Level 1, which represents the most basic cluster classification, three groups were found to be common clusters at Level 2.

Table 7 shows the findings for the year 2000, which are classified into three groups. Regarding the first cluster, relative rainfall variability is expected, whereby a city is determined to have a high resilience of sustainable function. This means that a city is well-equipped with conditions such as infrastructure, culture, medical welfare, and safety. The second cluster has a relatively high constant upward volatility of temperature and represents cities with high resilience of sustainable and maintenance function. The first and second groups have low resilience for basic and developmental functions. The third cluster is expected to have a relatively high environmental volatility of high temperature in summer, along with a constant upward volatility of temperature. It represents a place that has a relatively high resilience of basic and developmental functions.

Given the results of the analysis of the three groups for 2005, as shown in Table 8, the first cluster is expected to have a relatively high rainfall variability, representing cities with high resilience related to sustainable function. The second cluster is expected to have a relatively high level of high environmental volatility of temperature in summer, along with a continuous rising volatility of temperature. It represents places with a relatively high resilience of basic and developmental functions. This is similar to the characteristics of the third cluster for the year 2000. The third cluster has a relatively high continuous rising volatility of temperature, and a high resilience of sustainable and maintenance functions. This is similar to those of the second cluster for the year 2000.

As shown in Table 9, which illustrates the results of the analysis of three groups for the year 2010, an aspect of clusters that is different from the years 2000 and 2005 appeared. The first cluster has low climate variability and resilience of all functions. The second cluster has a relatively high resilience of developmental function but continuously rising volatility of temperature, rainfall variability, and high environmental variability of temperature in summer; all these elements are relatively high. The third cluster has an average level of resilience in all functions, even though high environmental volatility of temperature in summer is relatively high.

Table 3
Results of the factor analysis of climate variability values.

Rotated Factor Matrix[a]			
	Factor		
	1	2	3
Average temperature	0.962	0.029	−0.195
Maximum daytime temperature	0.824	−0.030	0.191
Minimum daytime temperature	0.749	0.063	−0.519
Annual precipitation	−0.006	0.343	0.139
Days of heat waves	−0.109	0.006	0.818
Days with tropical nights	−0.001	0.143	0.257
Intensity of rainfall	0.151	0.840	0.190
Rainy days	−0.075	0.689	−0.120

Factor Transformation Matrix[a]			
Factor	1	2	3
1	0.935	0.068	−0.349
2	0.066	0.931	0.358
3	0.349	−0.358	0.866

[a] Factor extraction method: Principal factor extraction (Principal axis factoring), Rotation method: Varimax with Kaiser normalization. Factor rotation was collected by repeatedly calculating five times.

Table 4
Fitness results of CFA of measurement variables for each year.

	χ^2 (p value)	Degree of freedom	Root Mean Square Error of Approximation (RMSEA)	Tucker–Lewis index (TLI)	Comparative fit index (CFI)	Goodness of fit (GFI)
2000	7904.147 (0.00)	740	0.205	0.276	0.313	0.340
2005	8344.4104 (0.00)	740	0.211	0.224	0.264	0.328
2010	8395.005 (0.00)	740	0.212	0.155	0.198	0.385

Table 5
Factor loading values of common variables for each year.

Function	Indicator	Measurement variable	Factor loading values		
			2000	2005	2010
Basic function	1. Safety of residential buildings	Rate of deteriorated housing	0.055029	0.038876	0.048414
	2. Risk characteristics of residential locations	Dangerous areas	0.004162	−0.03598	0.002614
		Rate of vulnerable residents	−0.02889	−0.02548	−0.01222
	3. Adequate housing supply	Housing supply rate	−0.05899	−0.02561	−0.00663
		Occupancy type	−0.17707	−0.13137	−0.07848
	4. Productivity	Degree of local tax payments	0.057698	0.015003	0.00491
	5. Diversity of industry	Degree of specialization in manufacturing	0.026106	0.006439	0.000982
		Diversity of industry	0.041079	0.006948	−0.00062
	6. Economic power of local governments	Available resources of local governments	0.056266	0.01709	0.008342
	7. Local industrial base	Local service workers	0.216228	0.059642	0.027112
	8. Employment opportunities	Stability of job	0.082597	0.016337	0.00596
		Number of new jobs created	0.116389	0.011933	0.002776
Developmental function	1. Knowledge-based industry	Foundation of creative industry	0.014175	0.013989	0.007001
		Degree of foundation	0.057614	0.057386	0.03097
	2. Innovation workforce	Professional science and technology services	0.039754	0.034125	0.027852
	3. Innovative capital and level	R & D investment expenditure	0.029629	0.017214	0.009773
		Total innovation index	0.008795	0.010794	−0.0002
	4. Foundation of social capital	Religious facilities	−0.00292	−0.00142	−0.00103
	5. Educational opportunities and standards	Educational facilities	−0.05836	−0.06294	−0.03991
		Educational level	0.209067	0.237364	0.23819
		Number of libraries	−0.00132	0.003885	0.00703
		Equity of education	−0.01946	−0.02338	−0.00773
	6. Influx of creative classes	Inflow of professional science and technology service workers	0.019603	0.010875	0.002128
Sustainable function	1. Opportunities for cultural leisure	Satisfaction with cultural leisure	0.093323	0.100691	0.002509
	2. Cultural cohesion	Cohesion of the community	0.470033	0.436456	−0.08467
	3. Natural environment	Green zones and parks	0.090865	0.099354	−0.01959
	4. Disaster damage	Degree of damage due to disasters	−0.02345	−0.0326	0.003281
		Mortality rate	−0.00421	−0.00701	−0.00195
	5. Social safety foundation	Number of basic livelihood security recipients	0.032492	0.048118	−0.01951
		Fire and police stations	−0.02464	−0.04379	0.009829
Maintenance function	1. Citizen participation	Degree of political participation	−0.02439	−0.07442	0.000477
	2. Administrative budget and manpower	Administrative personnel	−0.01684	−0.01552	0.088059
		Number of people working at administrative service agencies	−0.00216	−0.01798	−0.00424
		Processing complaints	0.013276	0.007147	−0.00326
		Financial self-reliance	0.006399	0.031619	−0.00253
		Recovery grants	−0.26745	−0.01085	0.000135
	3. Degree of response to disaster	Amount of damage due to natural disasters for 10 years	1.538152	1.671383	−0.00047
		Degree of recovery due to natural disasters for 10 years	−1.87129	−2.03892	−0.00045
	4. Disaster preparedness infrastructure	Drainage pumping station	−0.04165	−0.13449	−0.00072
		Transportation facilities	−0.00596	−0.03993	−0.00019

4.3. Spatial patterns of urban function indicators for resilience and type of clusters

Fig. 1 shows the spatial patterns of city for each function in 2000, 2005, and 2010. In 2000 and 2005, the sustainable and maintenance functions had a relatively narrow span of change, while basic and developmental functions had a relatively large span of change. The basic and developmental functions were strongly formed around large cities, including Seoul, Gyeonggi, Busan, Daejeon,

Table 6
Number of groups by level of inter-cluster distance.

	Distance	2000	2005	2010
Level 1	25	2	2	2
Level 2	20	3	3	3
Level 3	15	4	4	4
Level 4	10	5	4	4
Level 5	5	9	8	7

Table 7
Results of K-means clustering of urban resilience indicators in 2000.

Final cluster centers

	Cluster		
	Cluster 1	Cluster 2	Cluster 3
Continuously rising volatility of temperature	−0.686	1.083	0.311
Rainfall variability	0.097	−0.206	−0.031
High temperatures − Environmental variability in summer	−0.043	−1.709	0.472
Basic function	−0.430	−0.340	0.450
Developmental function	−0.260	−0.220	0.280
Sustainable function	0.520	0.220	−0.500
Maintenance function	0.020	0.060	−0.030

Distance between final cluster centers

	Cluster 1	Cluster 2	Cluster 3
Cluster 1	–	2.470	1.836
Cluster 2	2.470	–	2.604
Cluster 3	1.836	2.604	–

ANOVA

	Cluster		Error		F	Probability of significance
	Mean square	Degree of freedom	Mean square	Degree of freedom		
Continuously rising volatility of temperature	43.880	2	0.584	229	75.085	0.000
Rainfall variability	1.090	2	0.799	229	1.364	0.258
High temperatures – Environmental variability in summer	53.221	2	0.323	229	164.790	0.000
Basic function	21.263	2	0.193	229	110.015	0.000
Developmental function	7.939	2	0.069	229	115.422	0.000
Sustainable function	27.212	2	0.145	229	187.757	0.000
Maintenance function	0.108	2	0.010	229	10.416	0.000

Number of cases in each cluster

Cluster	Cluster 1	94.000
	Cluster 2	28.000
	Cluster 3	110.000
Validity		232.000
Missing		0.000

Daegu, Gwangju, and Ulsan. The sustainable function was largely found in non-metropolitan areas. The maintenance function had a lower value than other functions and did not have major significance except in certain areas. In 2010, the spatial pattern of urban function indicators for resilience differed from the patterns of 2000 and 2005. The high values of all urban function indicators were concentrated on metropolitan areas.

The type of clusters also changed over time. Fig. 2 shows the spatial distribution of each type of cluster in 2000, 2005, and 2010. Given the spatial characteristics of group-specific distribution in 2000, the first cluster is widely distributed in the middle and southwest of South Korea. Regarding the features of the first cluster, culture, participation, and safety are relatively high, although the functions of development related to industry, the economy, and existence are low. It is a place that is expected to have high variability of precipitation. The second cluster, representing the northeastern part of South Korea, includes parts of mountain areas in Gangwon-do and Gyeongsangbuk-do. Although it has features of resilience that are similar to those of the first cluster, the difference is that the item related to climate change has a constant upward volatility of temperature. The third cluster is distributed around the

Table 8
Results of K-means clustering of urban resilience indicators in 2005.

Final cluster centers

	Cluster		
	Cluster 1	Cluster 2	Cluster 3
Continuously rising volatility of temperature	−0.696	0.349	1.146
Rainfall variability	0.313	−0.227	−0.235
High temperature – Environmental variability in summer	−0.168	0.582	−1.698
Basic function	−0.160	0.180	−0.130
Developmental function	−0.210	0.250	−0.230
Sustainable function	0.370	−0.420	0.350
Maintenance function	0.090	−0.120	0.120

Distance between final cluster centers

	Cluster 1	Cluster 2	Cluster 3
Cluster 1	–	1.712	2.457
Cluster 2	1.712	–	2.611
Cluster 3	2.457	2.611	–

ANOVA

	Cluster		Error		F	Probability of significance
	Mean square	Degree of freedom	Mean square	Degree of freedom		
Continuously rising volatility of temperature	47.988	2	0.549	229	87.487	0.000
Rainfall variability	8.283	2	0.736	229	11.252	0.000
High temperatures – Environmental variability in summer	58.442	2	0.277	229	210.706	0.000
Basic function	3.122	2	0.047	229	66.129	0.000
Developmental function	6.111	2	0.100	229	61.350	0.000
Sustainable function	17.828	2	0.235	229	75.991	0.000
Maintenance function	1.347	2	0.084	229	15.989	0.000

Number of cases in each cluster

Cluster	Cluster 1	98.000
	Cluster 2	107.000
	Cluster 3	27.000
Validity		232.000
Missing		0.000

developed parts of metropolitan areas. Although the functions of existence (related to housing, industry, and the economy) and the development functions (including innovation and creation) are relatively high, the impact of a high temperature environment in summer is expected to be strong.

In 2005, the first cluster's spatial distribution is similar to the first cluster of the year 2000, and the second cluster in 2005 is similar to the third cluster for the year 2000. Although it is similar to the year 2000, which has the characteristics of non-metropolitan and metropolitan areas, it has a conurbation form from the metropolitan area to Chungcheongnam-do. The third cluster in 2005 is similar to the second cluster for the year 2000. This also appears in the northeastern part of South Korea, similar to the year 2000.

The first cluster of the group-specific spatial features of the distribution in 2010 appears in Gangwon-do, Gyeongsangbuk-do, and some inland zones. The second cluster appears in some parts of the metropolitan and northeastern coastal areas, and some parts of the southwestern and midwestern coasts. The third cluster is most widely seen across the whole region and does not have any results relating to analyzed characteristics.

5. Conclusions and discussions

5.1. Conclusions

The findings of this study showed that the city's functions for resilience are changing; these functions appeared totally different in 2010 than they did in 2000. However, whether these changes are temporary or due to a process of conversion cannot be known due to a lack of time-series data. What is clear is that the year 2010 has a form that is different from the past. The years 2000 and 2005 have cluster forms that are somewhat clearly distinguished. These years include types of areas with high rainfall variability and a relatively stronger resilience of cultural, medical, environmental, and social safety (which are sustainable functions of a city) compared to other

Table 9
Results of K-means clustering of urban resilience indicators in 2010.

Final cluster centers

	Cluster		
	Cluster 1	Cluster 2	Cluster 3
Continuously rising volatility of temperature	0.041	1.169	−0.494
Rainfall variability	−0.408	0.354	−0.058
High temperatures – Environmental variability in summer	−1.671	0.306	0.238
Basic function	−0.090	0.080	−0.010
Developmental function	−0.210	0.150	−0.020
Sustainable function	−0.080	0.050	0.000
Maintenance function	−0.040	0.030	0.000

Distance between final cluster centers

	Cluster 1	Cluster 2	Cluster 3
Cluster 1	–	2.437	2.026
Cluster 2	2.437	–	1.726
Cluster 3	2.026	1.726	–

ANOVA

	Cluster		Error		F	Probability of significance
	Mean square	Degree of freedom	Mean square	Degree of freedom		
Continuously rising volatility of temperature	57.663	2	0.464	229	124.269	0.000
Rainfall variability	6.506	2	0.752	229	8.656	0.000
High temperatures – Environmental variability in summer	50.051	2	0.351	229	142.741	0.000
Basic function	0.319	2	0.022	229	14.564	0.000
Developmental function	1.389	2	0.094	229	14.712	0.000
Sustainable function	0.171	2	0.012	229	14.752	0.000
Maintenance function	0.057	2	0.006	229	9.361	0.000

Number of cases in each cluster

Cluster	Cluster 1	31.000
	Cluster 2	59.000
	Cluster 3	142.000
Validity		232.000
Missing		0.000

functions. The years 2000 and 2005 also encompassed types of areas for which only the resilience of innovation, creation, and social capital (the developmental functions of a city) are high, although changes in the continuous rise in temperature and high temperature in summer are expected to be distinct. The years 2000 and 2005 also included types of areas with relatively high resilience regarding sustainable and maintenance functions, despite the relatively high volatility of increasing temperature. Seoul, Incheon, Gyeonggi-do, and some metropolitan areas were included in the second cluster, while Gangwon-do and mountainous regions were included in the third cluster. Others were included in the first cluster. However, such a pattern was not found for the year 2010, and the spatial pattern also changed. The clusters in the year 2010 represented areas with low climate variability and resilience related to all functions; the only types of resilience related to developmental functions were a continuous rise in temperature, rainfall, and high temperature, in addition to types of areas with environments that featured a high volatility of high temperatures and average resilience only. The first type included the inland areas of Gangwon-do and Gyeongsangbuk-do. The second type included parts of Seoul, Incheon, Gyeonggi-do, and coastal zones in Gangwon-do, as well as the west coast of parts of Chungcheongnam-do and Jeollanam-do. The third type included the remaining areas.

5.2. Discussion: implications for policy makers

By connecting urban resilience indicators in four categories of urban functions with climate variability, this study showed changes of urban functions and clusters in spatial units linked to climate factors. These results should impel policy makers to consider urban resilience and future research within the field of urban resilience.

The measurement variables and methods of urban resilience in conjunction with the urban function used in this study will be useful for policy makers to identify the tradeoff between variables and to develop policies accordingly. Discussions on existing urban resilience suggest the ambiguity of the scope of cities and measurement targets (Meerow et al., 2016) and the problems with urban

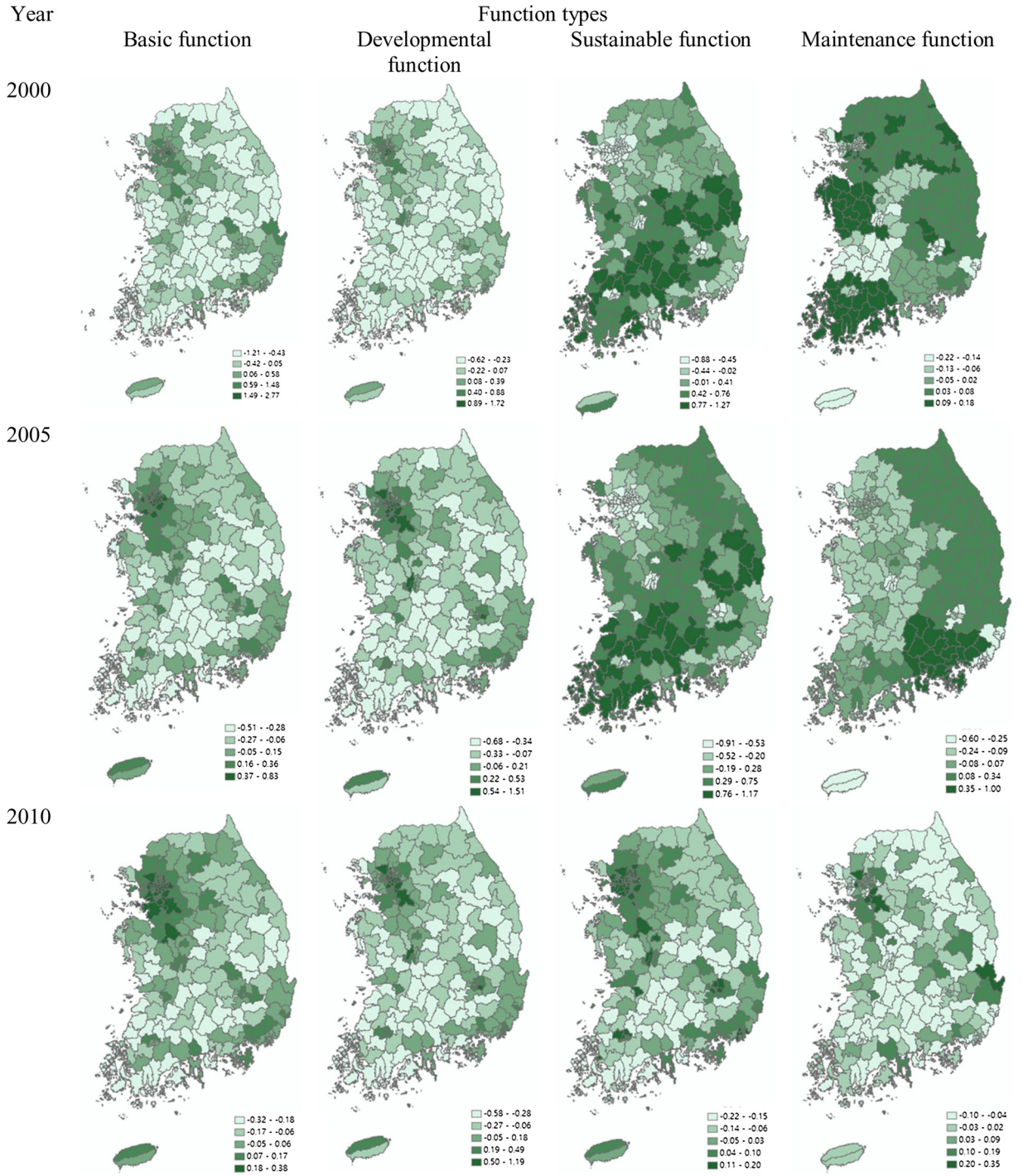

Fig. 1. Spatial patterns of urban function indicators.

system classification and linking it with measurement concepts (Tyler et al., 2014). In this study, we introduced a measurement that can take into account the characteristics of network and socioeconomic features in conjunction with the urban function, and we integrated it with factors of future exogenous (climate related) change. Following the resilience analysis established by Kotzee and Reyers (2016) and Hung et al. (2016), this study's method allows policy makers to use knowledge of the tradeoff between variables to create a plan. However, this study also has limitations in its ability to quantify the socio-economic and institutional variables related to resilience and to form dynamic variables in connection with the conceptual attributes of resilience. Therefore, in order to derive variables that can better measure the conceptual attributes of resilience, it is necessary to develop indicators that combine qualitative

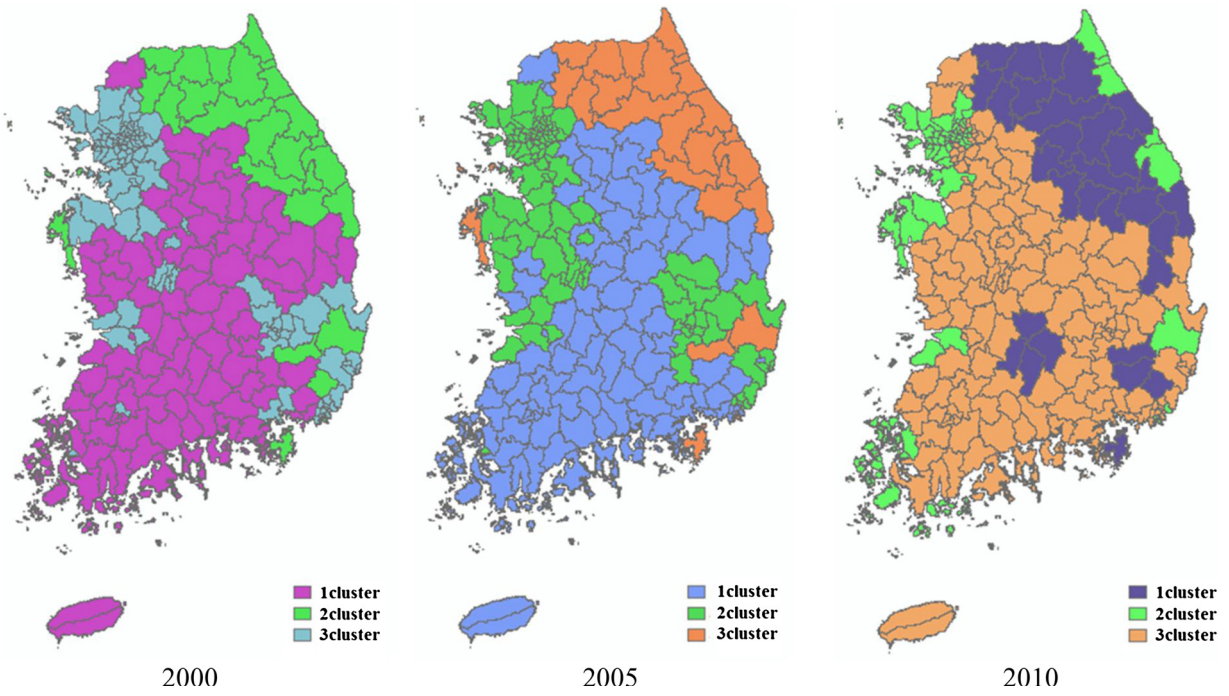

Fig. 2. Spatial distributions of each type of cluster.

and quantitative methods to measure the institutional and socio-economic factors that constitute the urban system. In particular, as the Rockefeller Foundation and ARUP Group (2014) suggests, a measurement tool that can reflect the intentions of the concept of resilience by using a performance-based approach will be a valuable feature of future studies. Such a tool will reduce the gaps in the relationship between conceptual attributes and measurement variables, as well as gaps in the constraints of statistical data.

It is necessary to study the relationship between the resilience indicator and climatic variability related to urban functions. In future policy discussions, it will be important to investigate the changes in the functions of a city's resilience and to examine the cause (s) thereof (Bruneau et al., 2003; Toubin, Laganier, Diab, & Serre, 2015). In order to construct a policy as a response to change, it is necessary to judge whether the cause of change is a short-term phenomenon or a socio-economic factor that will transform the urban system (Kim & Lim, 2016). It should be possible to determine whether the current state of socio-economic change is due to urban inertia, and this should influence policies regarding climate variability (van Drunen, van't Klooster, & Berkhout, 2011).

Future research on urban resilience measurement should focus not only on measuring resilience itself but also on factors that change resilience-related sub-functions and how climate change is based on these factors. In particular, it is necessary to study how the variables in the sub-function relate to other variables, what causes them, and how the types of variables change over time. Causes of events that change slowly over the medium to long term, as well as causes of short and rapid forms such as disasters should be identified. Doing so will enhance future prospects for urban change in relation to climate change and resilience, and will form the basis for policymaking related to climate change adaptation.

Local governments' climate change adaptation policies must incorporate consideration of time-series data regarding the climate factors that influence elements of a city. These entities face obstacles to successfully adapting to climate change, including lack of climate information, uncertainty and the lack of understanding of technological, financial, and cultural characteristics (Adger et al., 2007), lack of leadership (Burch, 2009) and local concerns (van Aalst, Cannon, & Burton, 2008), and lack of discussions with external decision-makers such as out-sourcing and privatization managed by local government (Carlsson-Kanyama, Carlsen, & Dreborg, 2013).

For local governments to overcome these barriers, deliberation and collaboration with various stakeholders is needed. Local governments should be able to persuade them to acquire resources and bring practical aims to deliberation and collaboration. This persuasion should be centered on current and continuously updated data-based processes, not normative perspectives on climate change.

This study presented 25 indicators that can be used to measure resilience in conjunction with the four functions in the city and examined how they changed over 10 years. However, in the year that this state could be fully understood, there was a limit to judging the time series tendency, which could be broken down into three parts. Therefore, the time-series data on actors such as residents, businesses, workers, etc., who collectively constitute a city, should be investigated and updated to include climate factors. This data will enable local government policymakers to understand the current status of their cities and guide subsequent policy development.

Acknowledgement

This study was supported by the research project of the Korea Environment Institute [Grant number 2016-02] and by the National Research Foundation of Korea (NRF) grant funded by the Korean Government (No, NRF-2017R1A2B4008057).

References

Adger, W. N., Agrawala, S., Mirza, M. M. Q., Conde, C., O'Brien, K., Pullhin, J., et al. (2007). Assessment of adaptation practices, options, constraints and capacity. In L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, & C. E. Hanson (Eds.). *Climate change 2007: Impacts, adaptation and vulnerability. Contribution of working group II to the fourth assessment report of the intergovernmental panels on climate change* (pp. 717–743). Cambridge: Cambridge University Press.

Beck, U. (1992). *Risk society: Towards a new modernity.* London: Sage.

Berkes, F., Colding, J., & Folke, C. (2003). *Navigating social-ecological systems: Building resilience for complexity and change.* Cambridge: Cambridge University Press.

Bonanno, G. A. (2004). Loss, trauma, and human resilience: Have we underestimated the human capacity to thrive after extremely aversive events? *American Psychologist, 59*(1), 20–28.

Brand, F. S., & Jax, K. (2007). Focusing the meaning(s) of resilience: Resilience as a descriptive concept and a boundary object. *Ecology and Society, 12*(1), 23.

Brugmann, J. (2012). Financing the resilient city. *Environment and Urbanization, 24*(1), 215–232.

Bruneau, M., Chang, S. E., Eguchi, R. T., Lee, G. C., O'Rourke, T. D., Reinhorn, A. M., et al. (2003). A framework to quantitatively assess and enhance the seismic resilience of communities. *Earthquake Spectra, 19*(4), 733–752.

Burch, S. (2009). Transforming barriers into enablers of action on climate change: Insight from three municipal case studies in British Columbia, Canada. *Global Environmental Change, 20*, 287–297.

Burton, C. (2012). *The development of metrics for community resilience to natural disasters. (Ph.D. thesis).* South Carolina: University of South Carolina.

Campbell, K. E., & Lee, B. A. (1992). Sources of personal neighbor networks: Social integration near or time. *Social Forces, 70*, 1077–1110.

Carlsson-Kanyama, A., Carlsen, H., & Dreborg, K.-H. (2013). Barriers in municipal climate change adaptation: Results from case studies using backcasting. *Futures, 49*, 9–21.

Carmin, J., Nadkarni, N., & Rhie, C. (2012). *Progress and challenges in urban climate adaptation planning: Results of a global survey.* Massachusetts: ICLEI and MIT.

Da Silva, J., Kernaghan, S., & Luque, A. (2012). A systems approach to meeting the challenges of urban climate change. *International Journal of Urban Sustainable Development, 20*(8), 1–21.

Davoudi, S. (2012). Resilience: A bridging concept or a dead end? *Planning Theory and Practice, 13*(2), 299–307.

Desouza, K. C., & Flanery, T. H. (2013). Designing, planning: And managing resilient cities: A conceptual framework. *Cities, 35*, 89–99.

Dicken, P. (2011). *Global shift: Mapping the changing contours of the world economy* (6th ed.). New York: Guilford Press.

Friend, R., & Moench, M. (2013). What is the purpose of urban climate resilience?: Implications for addressing poverty and vulnerability. *Urban Climate, 6*, 98–113.

Georgetown Climate Center (2017). *Policy considerations for the maryland commission on climate change.* Washington DC: Georgetown Climate Center.

Godschalk, D. (2003). Urban hazard mitigation: Creating resilient cities. *Natural Hazards Review, 4*(3), 136–143.

Hung, H. C., Yang, C. Y., Chien, C. Y., & Liu, Y. C. (2016). Building resilience: Mainstreaming community participation into integrated assessment of resilience to climatic hazards in metropolitan land use management. *Land Use Policy, 50*, 48–58.

Kim, D., & Lim, U. (2016). Urban resilience in climate change adaptation: A conceptual framework. *Sustainability, 8*, 405.

Korea Meteorological Administration (2012). *Climate change report on the Korea Peninsula*Seoul, Korea: KMA.

Kotzee, I., & Reyers, B. (2016). Piloting a social-ecological index for measuring flood resilience: A composite index approach. *Ecological Indicators, 60*, 40–53.

Leach, M. (2008). *Re-framing resilience: A symposium report*Brighton: STEPS Centre.

Leichenko, R. (2011). Climate change and urban resilience. *Current Opinion in Environmental Sustainability, 3*(3), 164–168.

Lu, P., & Stead, D. (2013). Understanding the notion of resilience in spatial planning: A case study of Rotterdam, The Netherlands. *Cities, 35*, 200–212.

Maryland Coast Smart Council (2017). *Maryland coast smart council 2016 annual report*Maryland: Department of Natural Resources.

Mayunga, J. S. (2009). *Measuring the measure: A multi-dimensional scale model to measure community disaster resilience in the U.S. gulf coast region. Ph.D. dissertation.* Texas A&M University.

Meerow, S., Newell, J. P., & Stults, M. (2016). Defining urban resilience: A review. *Landscape and Urban Planning, 147*, 38–49.

Moench, M., Tyler, S., & Lage, J. (2011). *Catalyzing urban climate resilience: Applying resilience concepts to planning practice in the ACCCRN program (2009–2011).* Institute for Social and Environmental Transition-International.

NOAA (2015). *Coastal community resilience indicators and rating systems.* South Carolina: Office for Coastal Management.

Osbahr, H. (2007). *Building resilience: Adaptation mechanisms and mainstreaming for the poor.* Oxford: Centre for the Environment, University of Oxford.

Pizzo, B. (2015). Problematizing resilience: Implications for planning theory and practice. *Cities, 43*, 133–140.

Resilience Alliance (2007). *Urban resilience research prospectus.* Canberra: CISRO, Arizona State University, and Stockholm University.

Rockefeller Foundation, & ARUP Group (2014). *City resilience framework.* New York: Rockefeller Foundation.

Satterthwaite, D., & Dodman, D. (2013). Towards resilience and transformation for cities within a finite planet. *Environment and Urbanization, 25*(2), 291–298.

Seeliger, L., & Turok, I. (2013). Averting a downward spiral: Building resilience in informal urban settlements through adaptive governance. *Environment and Urbanization, 26*(1), 184–199.

Shim, J., & Kim, C. (2015). Measuring resilience to natural hazards: Towards sustainable hazard mitigation. *Sustainability, 7*, 14153–14185.

Simmie, J., & Martin, R. (2010). The economic resilience of regions: Towards an evolutionary approach. *Cambridge Journal of Regions, Economy and Society, 3*(1), 27–43.

Smith, A., & Stirling, A. (2010). The politics of social-ecological resilience and sustainable socio-technical transitions. *Ecology and Society, 15*(1), 11.

Toubin, M., Laganier, R., Diab, Y., & Serre, D. (2015). Improving the conditions for urban resilience through collaborative learning of Parisian urban services. *Journal of Urban Planning and Development (ASCE), 141*(4), 05014021.

Tyler, S., Nugraha, E., Nguyen, H. K., Van Nguyen, N., Sari, A. D., Thinpanga, P., et al. (2014). *Developing indicators of urban climate resilience (Climate resilience working paper No. 2).* Institute for Social and Environmental Transition-International.

Vale, L. J., & Campanella, T. J. (2005). *The resilient city: How modern cities recover from disaster.* New York: Oxford University Press.

White, I., & O'Hare, P. (2014). From rhetoric to reality: Which resilience, why resilience, and whose resilience in spatial planning? *Environment and Planning C: Government and Policy, 32*, 934–950.

Wilkinson, C., Porter, L., & Colding, J. (2010). Metropolitan planning and resilience thinking: A practitioner's perspectives. *Critical Planning, 17*, 2–20.

Yañez, K. (2012). What might a resilient city look like? In J. Da Silva, & E. Parker (Eds.). *Visions of a resilient city* (pp. 5–13). London: ARUP.

Zhao, P., Chapman, R., Randal, E., & Howden-Chapman, P. (2013). Understanding resilient urban futures: A systemic modelling approach. *Sustainability, 5*(7), 3202–3223.

van Aalst, M. K., Cannon, T., & Burton, I. (2008). Community level adaptation to climate change: The potential role of participatory community risk assessment. *Global Environmental Change, 18*, 165–179.

van Drunen, M. A., van't Klooster, S. A., & Berkhout, F. (2011). Bounding the future: The use of scenarios in assessing climate change impacts. *Futures, 43*, 488–496.